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Gulf Region
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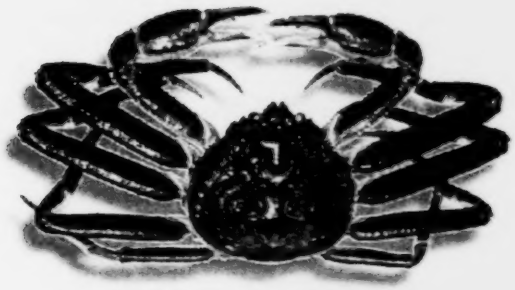
REFERENCE POINTS CONSISTENT WITH THE PRECAUTIONARY APPROACH FOR SNOW CRAB IN THE SOUTHERN GULF OF ST. LAWRENCE



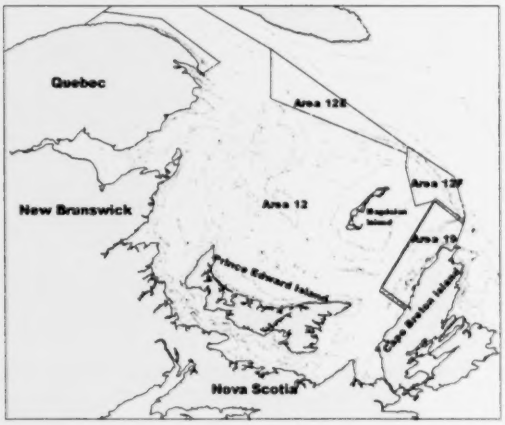


Figure 1. Map of the southern Gulf of St. Lawrence showing the Crab Fishing Areas.

Context :

Canada, as signatory to the United Nations Agreement on Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks (UNASF) has committed to using the Precautionary Approach (PA) in managing stocks. In 2009, DFO completed a policy document entitled "A fishery decision-making framework incorporating the Precautionary Approach" which explains in detail how the precautionary approach will be put into practice. To be compliant with the PA, fishery management plans should include harvest strategies that incorporate a Limit Reference Point that defines the critical / cautious zones and an Upper Stock Reference that delimits the cautious / healthy zones on the stock status axis, and a Removal Reference that defines the maximum removal rate in the healthy zone. DFO Fisheries and Aquaculture Management (DFO FAM) requested advice from science to define the reference points which could be used to develop the precautionary approach framework for the management of the snow crab stock from the southern Gulf of St. Lawrence. Guided by the DFO policy on the PA for fisheries, the review of options for and definition of reference points was conducted within a regional advisory process meeting which reviewed the status of the snow crab stock in the southern Gulf of St. Lawrence, Feb. 22 to 26, 2010. The review was provided by participants from DFO Oceans and Science, DFO FAM, a scientist from the US National Marine Fisheries Service, from provincial governments, from the fishing industry and from First Nations communities.

SUMMARY

- The abundance of commercial-sized (>= 95 mm carapace width) adult males is proposed as the indicator of stock status to guide fishing activities in the PA framework.
- Managing under the assumption that large commercial-sized adult male recruitment is at least in part dependent upon the abundance of large commercial-sized adult male mating stock results in the least risk to the resource.
- The estimate of B_{MSY}, which equals, 42,400 t, was derived using 50% of the maximum biomass over a productive period, 1997 to 2008.
- The upper stock reference point (B_{USR}) is estimated to be 34,000 t of commercial-sized adult male crab.
- The limit reference point (B_{lim}) is 9,400 t and represents the lowest biomass of hard shelled commercial-sized adult male crab which produced a good recruitment rate of juvenile crab.
- The estimate of F_{lim} is an annual exploitation rate of 0.401 (harvest in year t+1 divided by biomass in year t estimated from the trawl survey).
- The lack of a demonstrated stock and recruitment relationship, the extent of density dependent effects across cohorts, and the role of environmental variability in modifying growth and survival for snow crab are the major sources of uncertainty presently limiting the development of reference points not based on proxy methods.
- These interim reference points are specific to the snow crab biological unit from the southern Gulf and should be re-examined and revised as new information is obtained.

BACKGROUND

Snow crab (*Chionoecetes opilio*) is a crustacean like lobster and shrimp, with a flat, almost circular, body and five pairs of spider-like legs. The hard outer shell is periodically shed in a process called moulting. Unlike many other crustaceans, snow crabs do not continue to moult throughout their lives and maturity is characterized by a terminal moult. Females stop growing when they mature at shell widths less than 95mm. Male maturity also occurs with a terminal moult, is characterized by the development of large claws on the first pair of legs, and can occur at shell widths between 40 and 150 mm. The average difference of two to three years at terminal moult between males and females causes a sexual size/age dimorphism with males older and larger than females. Life expectancy after terminal moult for both males and females is typically four to six years. Snow crab reproduction dynamics are complex and involve paired matings with intense competition for mating partners between males and potentially as well between females. Females have spermathecae and can store sperm for fertilizing multiple batches of eggs without re-mating. In the southern Gulf of St. Lawrence, eggs are carried under the abdomen by females for about two years before hatching. The eggs hatch in late spring or early summer and the newly-hatched crab larvae spend 12-15 weeks floating freely in the water column. At the end of this period, they settle on the bottom. It takes at least 8-9 years (post-settlement, 10-11 years post mating) for males to reach carapace sizes >=95 mm, the legal size for harvest in the commercial fishery. In this document, large adult males refers to terminal moulted male crab of carapace width >= 95 mm.

Large adult males are considered to have a particularly beneficial role to reproduction compared to smaller mature males (Sainte-Marie et al. 2008). Large males can out-compete small males for females and they tend to mate with larger females. Large males can deposit larger sperm loads and female clutch size is positively correlated to sperm load and female size. Large males may clutch females for longer period thus affording protection from predation, harassment and loss of eggs. In a large number of studied populations of crab species, the abundance of adult crab is characterized by large oscillations with strong autocorrelation patterns in year class abundance (Orensanz et al. 1998). The oscillations in snow crab have been attributed to competition among year classes with large crab competing with and consuming smaller crab of younger age groups (Sainte-Marie et al. 1996).

Fishery

The commercial fishing season for snow crab in the southern Gulf of St. Lawrence typically occurs from April to September, depending on the management area. Baited traps, constructed of wire or tubular steel, are used to catch crab, mainly on mud or sand-mud bottoms at temperatures ranging from -0.5 to 4.5°C, and depths ranging from 50 to 280 m. Management of the fisheries is based on quotas and effort controls (number of licenses, trap allocations, trap dimensions, and seasons). The minimum legal carapace size for retention in the fishery is 95 mm and females are not harvested. Soft-shell and white-crab, crab which have recently moulted and for which the carapace has not fully hardened, are of lower economic value and are not of interest to the fishery.

The fishery grew quickly from its inception in 1966, peaking at 33,400 t in 1982 before dropping to the lowest catch level of the time series in 1990 at 8,900 t. Landings have fluctuated since with peaks in 1995 of 22,750 t and in 2005 of 36,200 t. Over the 1999 to 2008 time period, the harvest of snow crab in the southern Gulf of St. Lawrence averaged 25,000 t annually.

ANALYSIS

Snow crab from the southern Gulf of St. Lawrence is considered to consist of a single biological unit. The assessment of snow crab in the southern Gulf is based on a scientific bottom trawl survey that samples the entire known distribution of snow crab in the area and provides estimates of abundance by sex, size, stage of maturity and carapace condition. The trawl survey is conducted from July to September. The most recent assessment is provided by Hébert et al. (2009). An index of mature females that participated in mating in the spring of a given year (the year class) was calculated as the sum of new terminal moult females (called primiparous female) and half of the older terminal moult females (also called multiparous females) as the egg incubation and mating frequency is assumed to be two years for snow crab from the southern Gulf of St. Lawrence.

Interpretation of serious harm for snow crab

In the context of the Precautionary Approach (PA), when a stock is in the critical zone, its status has declined to such a low level that it is considered to be in a precarious state and productivity has been sufficiently impaired to cause serious harm (DFO 2004). The PA fishery decision making framework defines serious harm as negative impacts to the resource in the form of impaired productivity that would be serious or difficult to reverse (DFO 2009). A system has been harmed if it has lost resilience, meaning both the ability to recover from large perturbations and the ability to recover quickly from perturbations. Serious harm could be done to the species itself, to the ecosystem, and to the species component which is valued by people (for snow crab this is

the commercial-sized adult male crab). A loss of the component valued by people may also result in serious harm to the species, to productivity of the stock, and to the ecosystem.

Serious harm would have occurred to the species if there had been a permanent (or sustained for one or more generations) loss of a phenotype (large size at maturity for male crab) which has evolved as a life history strategy. Size-at-adulthood is considered to be at least in part heritable in snow crab because sexual size dimorphism favouring males is particularly well developed in this species and is usually the product of sexual selection, one of the strongest and most rapid-acting evolutionary forces (Shuster and Wade 2003). The environment, in particularly temperature, cannot be controlled and it can play a synergistic or antagonistic role to fishing, by increasing or reducing the male population component that becomes vulnerable to fishing (through a change in size-at-adulthood) and the spatial scales for density-dependent processes (through habitat contraction or expansion).

Managing risk of serious harm

The abundance of commercial-sized adult males (>= 95 mm) is proposed as the indicator of stock status to guide fishing activities in the PA framework for the following reasons:

1. it is the life stage which is exploited and valued to the fishery, and whose abundance can therefore be directly affected by the fishing activity, and
2. it is hypothesized to have a particular value to reproductive capacity of the stock and to its resilience, as described above.

In a risk management framework, the objective is to minimize the negative consequences to the valued component of management decisions based on an assumed recruitment dynamic which is incorrect. There are two competing hypotheses regarding the value of conserving some large commercial-sized male mating stock, two management options and four possible consequences to the resource (Table 1). Managing under the assumption that large commercial-sized adult male recruitment is at least in part dependent upon the abundance of large commercial-sized adult male mating stock results in the least risk to the resource regardless of which recruitment dynamic hypothesis is correct. The greatest risk to the resource (loss of recruitment of large commercial-sized adult male crab) is to manage assuming that commercial-sized adult male recruitment does not depend upon commercial-sized adult male reproductive stock.

Defining reference points for southern Gulf snow crab

There are presently no reference points defined for any of the snow crab stocks in eastern Canada.

The information available for the southern Gulf of St. Lawrence snow crab allows an exploration of some population dynamics of snow crab which can assist in the definition of reference points. Recruitment to Instar VIII (7 years old, post-mating) is positively associated with the abundance of females having laid a clutch of eggs (mated female) seven years earlier. The observed variability in the recruitment rate (per female) to Instar VIII is not seemingly associated with the abundance of commercial-sized adult males (post-fishery) or the abundance of all adult males (post-fishery) but moderately (within the time series) high recruitment rates were achieved at commercial-sized adult male abundances of about 12,000 tons (20 million animals) (based on post-fishery estimates of crab of hard-shell), the lowest levels within the time series of assessment (Figure 2).

Table 1. Consequences to abundance of large commercial-sized adult males when exploitation is managed relative to competing hypotheses.

Biological hypotheses: Large male recruitment depends upon mature female abundance, subsequent juvenile abundance and	Management options	
	Manage assuming hypothesis 1 is correct	Manage assuming hypothesis 2 is correct
(1) especially upon commercial-sized adult male abundance	Best option to reduce the risk of losing commercial-sized adult male recruitment	High risk of losing the commercial-sized adult male component
(2) regardless of commercial-sized adult male abundance	No added risk of losing commercial-sized adult male recruitment. Some loss to the fishery.	No added risk of losing commercial-sized adult male recruitment. No loss to the fishery.

DFO (2009) provides guidance on the derivation of both the stock status (biomass) and removal rate reference points for the PA framework. The stock would be in the critical zone if the stock status indicator is less than or equal to 40% of B_{MSY}. The stock would be in the healthy zone if the stock status indicator is above 80% of B_{MSY}. Another proxy limit reference point considered is called $B_{recover}$, the lowest historical biomass level from which the stock recovered readily or produced good recruitment (DFO 2002, 2004).

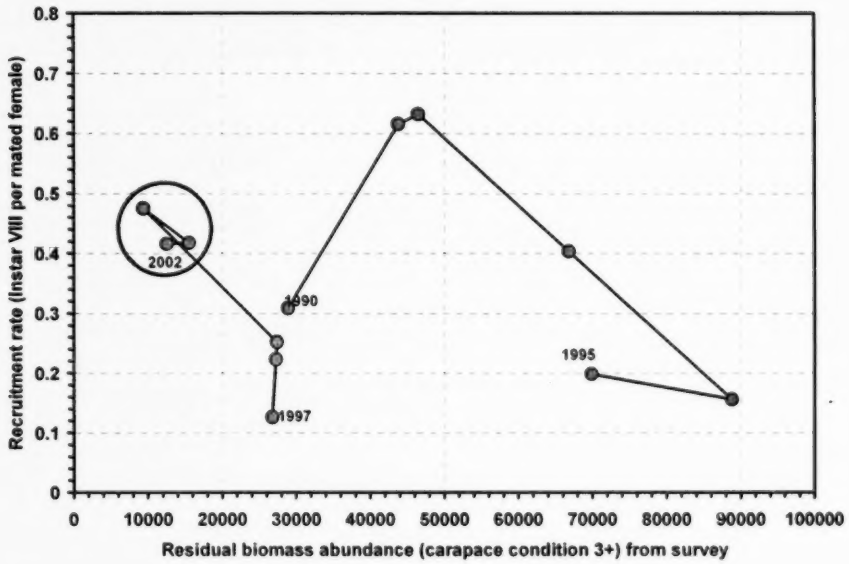


Figure 2: Recruitment rate (Instar VIII per mated female) by year class versus biomass of commercial-sized adult male crab of carapace condition 3 to 5 after the fishery, as estimated from the trawl survey.

In the absence of an estimate of B_{MSY} from an explicit model, as is the case for snow crab from the southern Gulf, a provisional estimate of B_{MSY} was taken as 50% of the maximum biomass over a productive period, 1997 to 2008 (Figure 3; DFO 2009). During this time period, the maximum biomass value was estimated in 2004 at 84,400 t. This translates to a B_{MSY} value of 42,400 t (Figure 3). It is unknown if this is a sustainable level (i.e. a good proxy for B_{MSY}) because

recruitment of terminal moulted large males from these biomass levels has only been measured for a few year classes to date.

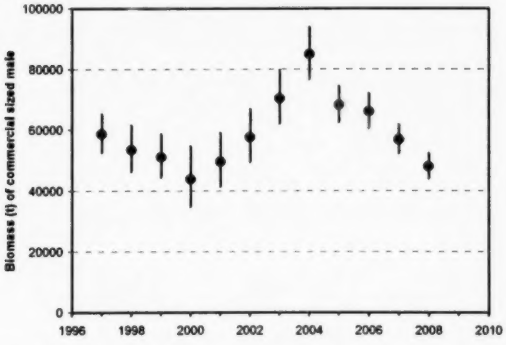


Figure 3: Biomass (t) of commercial-sized adult male crab (all carapace conditions) estimated from the trawl survey in the southern Gulf of St. Lawrence.

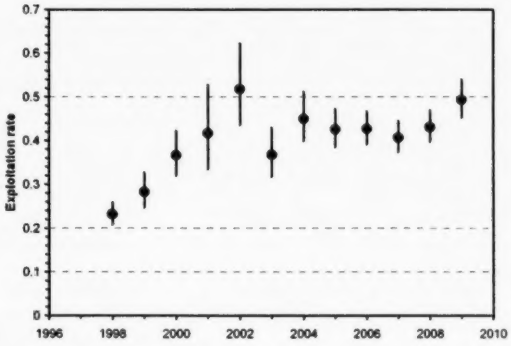


Figure 4: Exploitation rate (expressed as catch in year t divided by trawl survey biomass estimate in year t-1) for the fishing years 1998 to 2009 in the southern Gulf of St. Lawrence.

The upper stock reference point (B_{USR} = 80% of B_{MSY}) is 34,000 t of commercial-sized adult male crab of all carapace conditions as estimated from the trawl survey (Figure 3). These crab become hard shelled commercial-sized adult male crab as of 1 January of the year following the trawl survey. The limit reference point for the stock status was chosen as the lowest biomass of hard shelled commercial-sized adult male crab (post-fishery estimated from the trawl survey) which produced good recruitment rates of juvenile crab at Instar VIII (Figure 2). This B_{lim} ($B_{recovery}$) value is 9,400 t.

Consistent with the United Nations Fish Stock Agreement (UNFSA) F_{MSY} (the fishing mortality which gives the maximum sustainable yield) is the minimum standard for the removal reference in the application of the PA to fisheries. In the context of the Canadian framework for the PA, the exploitation rate in the Healthy Zone should not exceed F_{MSY}. In the absence of an explicit model, a provisional estimate of F_{MSY} for snow crab from the southern Gulf was taken as the average exploitation rate over the same period used to estimate B_{MSY}. The F_{lim} value was calculated at 0.401, the average exploitation rate (harvest in year t divided by biomass in year t-1 estimated from the trawl survey) over the 1998 to 2009 fishery period (Figure 4).

The recent history of stock performance relative to these reference points is shown in Figure 5. The decision rule for defining the exploitation rate in the cautious zone (along the F_{lim}/B_{USR} point down to the B_{lim} point) remains to be defined.

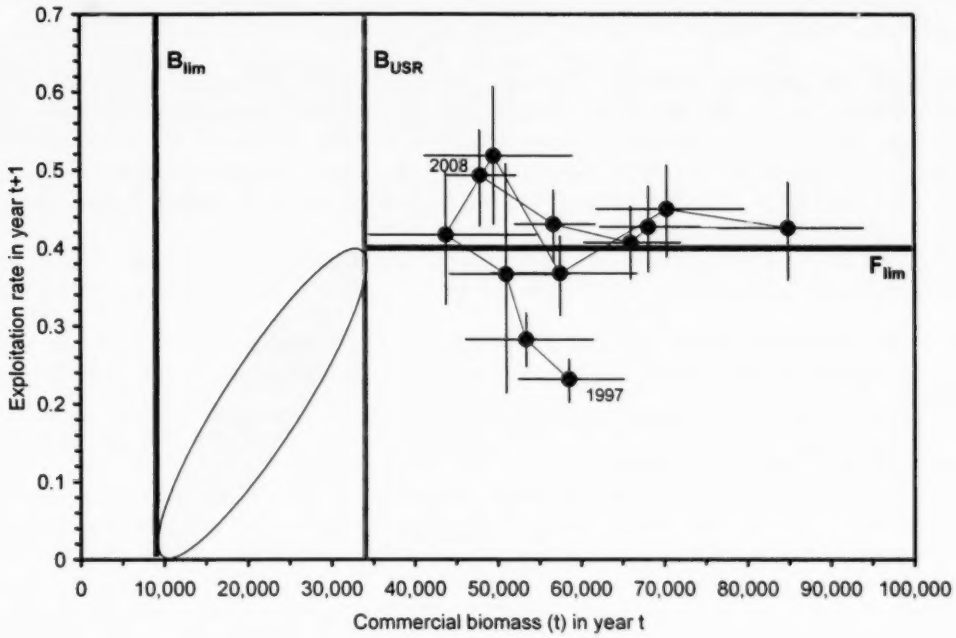


Figure 5: Trajectory of the southern Gulf of St. Lawrence snow crab stock along the stock status axis (biomass of snow crab (t)) and the exploitation rate axis (catch / biomass) for the 1997 to 2008 survey years.

CONCLUSIONS AND ADVICE

The interim reference points for snow crab from the southern Gulf of St. Lawrence are summarized in the table below. The biomass reference points are expressed as weight of commercial-sized adult male crab of hard shell carapace condition as of 1 January of the fishing year.

Reference point	Value
B_{MSY} (weight of commercial-sized adult male crab)	42,400 t
B_{USR} (weight of commercial-sized adult male crab)	34,000 t
B_{lim} (weight of commercial-sized adult male crab)	9,400 t
F_{lim} (annual exploitation rate)	0.401

The snow crab stock from the southern Gulf has shown important variations in biomass of adult males and females (Hébert et al. 2009). Some of the variations in abundance are likely the result of intra-specific density dependent effects expressed at earlier life stages.

The annual loss of commercial-sized adult male crab from all sources has averaged 66% over the recent period 1998 to 2009 (Z = instantaneous rate of loss = 1.11). The residual biomass (post-fishery) of commercial-sized adult male crab has been less than 10,000 t (about 20 million animals) once (in 2000) over the past 22 years. Some of the variability in abundance is

considered to be attributable to factors other than fishing. Annual loss rates of mature females, which are not fished, averaged 28% (Z = 0.33) over the recent time period 1998 to 2009.

Predictions of the consequence to recruitment (ten years into the future) of managing adult snow crab abundance remain difficult as the recruitment mechanisms are considered to be complex and involve feedback over multiple cohorts. The lack of a demonstrated stock and recruitment relationship, the extent of the density dependent effects across cohorts and the life stages over which such effects are manifested (due to cannibalism or space limitations), and the role of environmental variability in modifying growth and survival for snow crab are the major sources of uncertainty presently limiting the development of reference points not based on proxy methods described in the DFO PA policy (DFO 2009).

These interim reference points are specific to the snow crab biological unit from the southern Gulf of St. Lawrence and should be re-examined and revised as new information becomes available.

OTHER CONSIDERATIONS

The risk analysis framework for evaluating catch options relative to these reference points has been developed for the snow crab stock of the southern Gulf of St. Lawrence and should be used for the provision of catch advice consistent with the PA. Although there is no explicit rule for the risk which should be chosen in the context of limit reference points, consideration should be given to selecting a risk level which provides a low probability of falling below B_{lim} or exceeding F_{lim}.

For fisheries that target a specific sex, such as the snow crab fishery does for commercial-sized adult males, sex ratios should be a consideration in reference point definitions (Orensanz et al. 1998). It has been suggested that reference points in invertebrate species could also be based on setting a minimum abundance of spawners to take advantage of favourable environmental conditions, or maintaining a minimum density of mature animals in an area to ensure successful fertilization, or the establishment of refugia have been proposed for exploited marine crab species (Orensanz et al. 1998; Smith 2003).

The interim reference points for southern Gulf snow crab could be considered in concert with other indicators of population status including abundance of juvenile and intermediate stages, sex ratios of mature males and females, and others (Caddy et al. 2005).

Guidance on the development of the decision rule to define the exploitation rate trajectory in the cautious zone is provided in the PA policy (DFO 2009). The development of the decision rules to guide fishing exploitation, which is an essential element of the application of the PA, is dependent upon the realization of a sustainable balance between fishing capacity (which affects exploitation) and resource availability. Socio-economic factors such as the number of fishing licenses and the distribution of allocations among fleets is a concern of industry and are important considerations for management decision-making as these may have an effect, over time through exploitation decisions, on the reproductive dynamic of commercial-sized adult males as well as the resilience of the stock.

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